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(71) Applicant
Imperial Chemical Industries PLC

(Incorporated in the United Kingdom)

Imperial Chemical House, Millbank, London, SW1P 3JF, United Kingdom

(72) Inventors
Roy Hardwick
David Grahame Nowell

(74) Agent and/or Address for Service
Thomas James Reid
Imperial Chemical Industries PLC, Legal Department: Patents, PO Box 6, Shire Park, Bessemer Road, Welwyn Garden City, Hertfordshire, AL7 1HD, United Kingdom

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(54) **Making explosively clad metal sheet**

(57) A metal cladding layer is explosively bonded to a metal substrate to form a composite metal ingot; two ingots (10, 22) are then assembled with the cladding layers (14, 26) facing an intermediate parting layer (18) and the assembly is hot rolled to reduce the thickness and expand the area of the ingots simultaneously. The substrate may be carbon steel and the cladding layer may be nickel/chrome alloy. A steel edge strip (28) may be fusion welded around the interface of the ingots (10, 22) before rolling. The parting layer may be glass fibre tissue or chromic oxide. The method eliminates curling of the rolled sheet, facilitates the making of thinner clad sheets and reduces heat dissipation at the critical area of the bond interface during rolling.

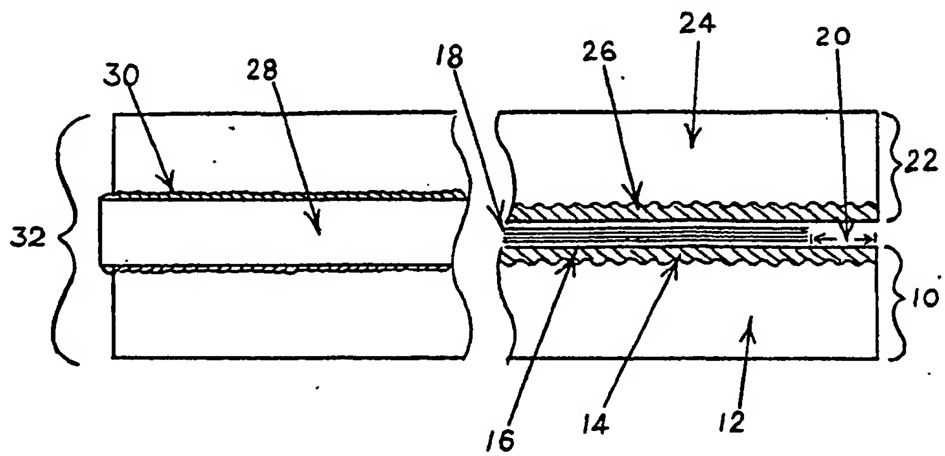

FIG 1

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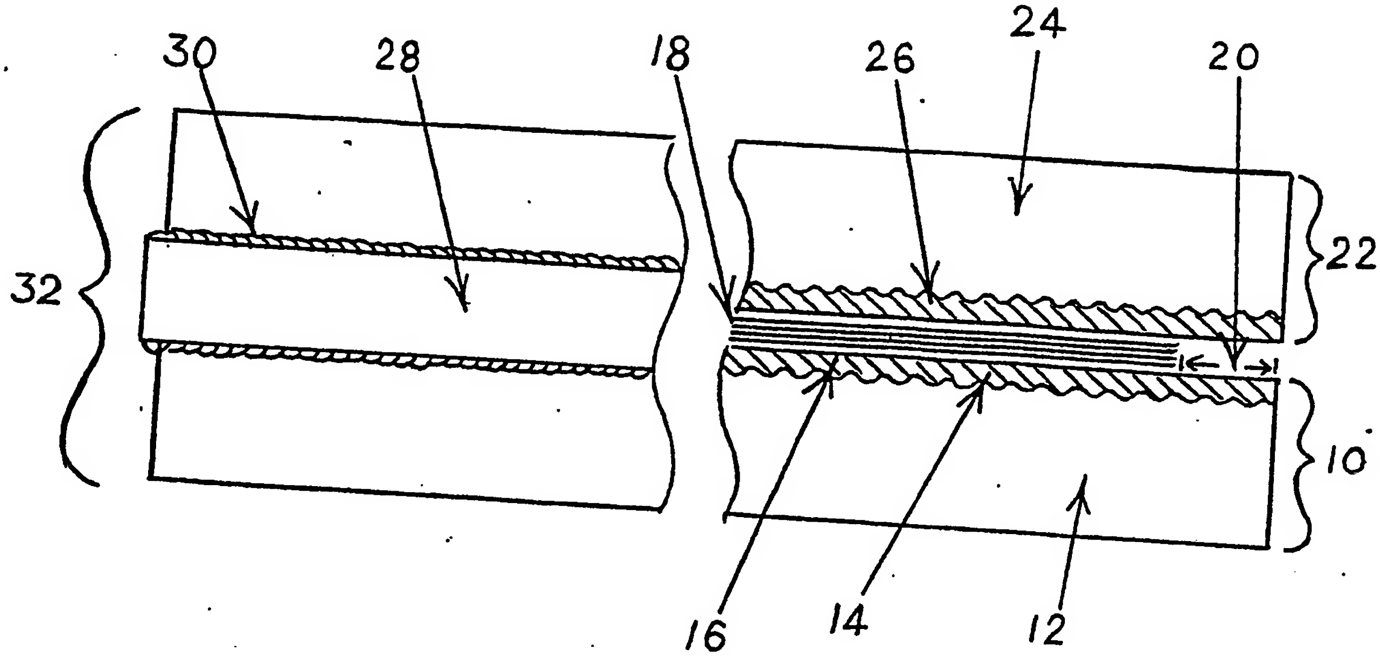

FIG 1

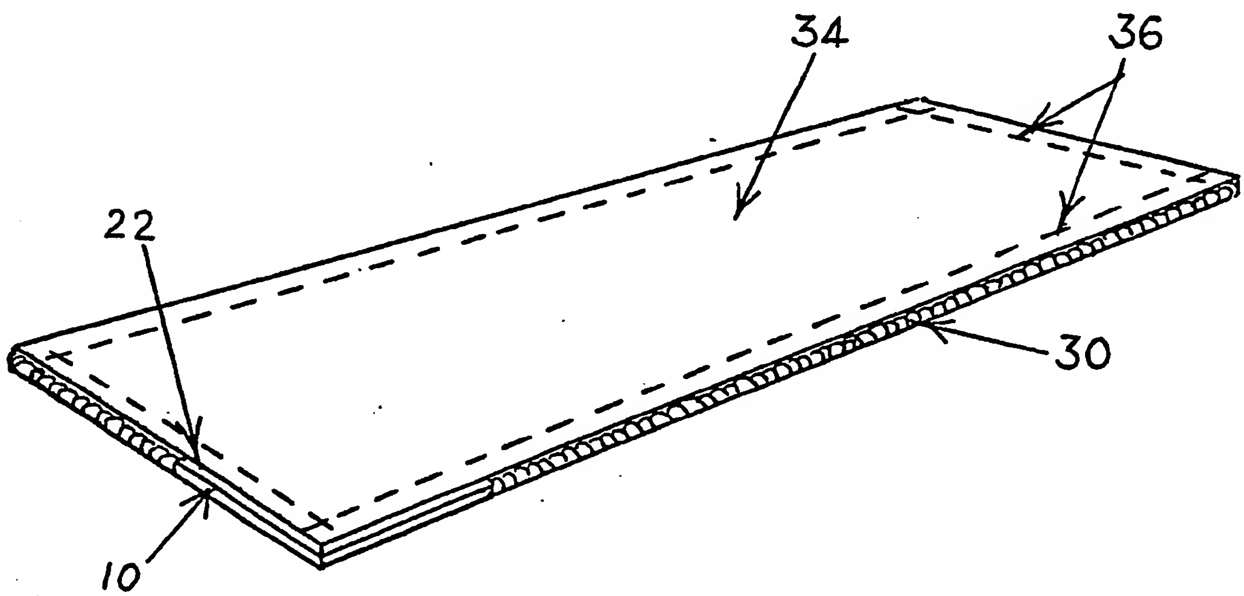

FIG 2

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EXPLOSIVELY BONDED CLAD METAL SHEET

This invention relates to an improved method of making explosively bonded clad metal sheet. The method is especially useful for making clad sheet from metals which cannot be readily bonded by hot rolling techniques, for example, clad sheets wherein the cladding has higher yield strength than the substrate.

The production of clad metal sheet by the process of hot roll bonding is well known. The process consists of placing a layer of relatively expensive metal, for example corrosion resistant metal, upon a substrate of less expensive metal, usually carbon steel, heating the assembly to the bonding temperature, and passing the assembly through a rolling mill to effect bonding at the layer interface.

The principle disadvantage of the process arise from limited compatibility of the component metals. In order to achieve successful bonding the following requirements must be satisfied:-

a) The component metals must have similar atomic spacing so that electron sharing occurs between a maximum number of atoms at the limited pressures attainable in the process.

b) The yield strength of the two materials must lie between close limits so that one material is not rolled preferentially resulting in a disproportionate increase in its surface area which precludes bonding.

These requirements impose severe limitations upon the range of material combinations which can be bonded. In practice, roll bonded metal combinations are limited to those in which the cladding yield strength is lower or similar to that of the substrate material. Success in roll bonding is less when the yield strength of the cladding material

exceeds that of the substrate and becomes less practical as the cladding yield strength increases.

For certain combinations of metal substrate and cladding it is advantageous to form the clad plate by the well known explosive bonding process wherein the cladding and substrate are progressively impelled together by means of the detonation of an overlying layer of explosive to effect progressive bonding on collision of the metal layers at the metal interface. This bonding process has been described in United Kingdom Patent Specifications nos. 923746, 1032019, 1168 264 and 1248794.

The explosive bonding process overcomes the above mentioned problem of material incompatibility. However, the size of plate which can be produced directly by explosive bonding is limited in area and thickness. The area is limited by the explosive detonation run length which is related to cladding thickness. The characteristic wavy interface of the explosively bonded metal composite increases in amplitude as a function of distance from the explosive initiator. With thin cladding, a point is quickly reached where the wave amplitude represents a major proportion of the cladding thickness and failure occurs in the form of cracks in the cladding. If the pre-bonding assembly has a large area and the substrate is relatively thin, the handling and transporting of the flexing components become impracticable. Thus, in practice, clad sheets are generally required to be of larger area and thinner than can be conveniently produced directly by the explosive bonding process. A method of overcoming this difficulty is to prepare a clad metal ingot of smaller area and greater composite thickness by the explosive bonding route and then hot roll the ingot down to the required final thickness. The ratio of the cladding/substrate thickness of the ingot is maintained throughout the onward rolling as area is increased and thickness reduced. This process is well

known and frequently used, but the following difficulties have been found in its practical application:-

a) Divergence between the yield strengths of the two materials of the metal combination, if excessive, causes the lower yield strength material to tend to reduce in thickness preferentially. The explosive bond prevent this but the result is a curling of the composite sheet away from the lower strength material. If the cladding is placed uppermost when rolling, the composite sheet will curl upwards around the upper roller. If rolled with the cladding downwards, the composite sheet will curl downwards onto the roller bed of the mill where it can become lodged between the rolls. In both cases, the composite sheet can be irrevocably damaged and serious damage to the explosive mill equipment can also result.

b) The bonding process is normally carried out in conventional steel rolling mills and levels of cleanliness are such that unless the mill is cleaned before each rolling operation, contaminants are rolled into the clad surface. As the clad thickness is relatively thin for commercial reasons, this thickness can be penetrated by the rolled-in contaminants thus rendering the plate useless in these areas. The frequent, thorough cleaning of the mill adds significantly to the cost of the product.

c) For commercial reasons, the overall thickness of the clad composite sheet must often be very small. It is difficult to roll down to small thicknesses on plate rolling mills as a point is reached where the rolls open under pressure by an amount equal or greater than the thickness of the plate being rolled. This prescribes the minimum thickness capability of the mill which is often greater than the desired thickness. To reach this desired thickness it would

then be necessary to continue rolling at a sheet or strip mill which then usually will impose limits upon the width of sheet which can be obtained.

d) As the composite sheet thickness is reduced and its area extended, the composite sheet being rolled cools much more rapidly. Often the upper and lower limits of rolling temperature are fairly close together and, when this is the case, the rapid cooling of the composite sheet as it reduces in thickness makes it increasing difficult to maintain the minimum required temperature.
The extensive area dimensions which have been reached at this stage are such that re-heating of the composite sheet is precluded as it is generally larger than the furnaces which are available. Often, the upper limit of rolling temperature must be fairly low in order to avoid the growth of intermetallic substances at the bond interface and consequently the minimum rolling temperature beyond which the mill is overstressed is quickly reached.

We have found that these disadvantages may be overcome by rolling the explosively bonded composite ingots in pairs, each pair of ingots being placed together, clad face adjacent to clad face, with a parting agent interposed between to prevent roll bonding of the like materials during subsequent hot rolling of the composite assembly. Accordingly, the present invention consists in a method of making explosively clad metal sheet wherein a relatively thick metal cladding layer is explosively bonded to a relatively thick metal substrate to form a composite metal ingot and the ingot is reduced in thickness and extended in area by hot rolling, characterised in that before rolling, two ingots are assembled with the cladding layers facing an intermediate parting layer of inert material and the assembly is rolled to reduce the thickness and expand the

area of the ingots simultaneously. The parting layer advantageously comprises one or more layers of glass fibre tissue or a coating of chromic oxide. The two ingots are preferably bonded together by a metallurgical bond around the periphery of the interface to maintain register of the components during rolling. The bond may conveniently comprise tack welding but if the cladding materials are difficult and expensive to fusion-weld in this way an alternative method is to locate a steel strap overlapping the exposed cladder edges, the two edges of the steel strap then being fusion-welded to the steel substrates.

The assembled composite ingots may be heated and rolled in the same manner as a single steel ingot to an overall thickness which is twice that of the required final thickness of the single composite sheet. The rolled composite sheets may be flattened in the conventional manner before shearing off any fusion welded edges and the two rolled down plates may be readily separated from each other.

Conveniently the explosively bonded ingots have a substrate thickness in the range from 20 to 200 mm and a cladding thickness in the range from 2 to 30 mm and are rolled down to form a clad sheet having a substrate thickness in the range from 3 to 50 mm and a cladding thickness in the range from 0.5 to 5 mm. The invention is especially advantageous in the manufacture of explosively bonded clad sheets wherein the cladding comprises a nickel/chrome alloy on a carbon steel substrate.

The advantages of the invention method are:

a) The composite assembly remains essentially flat during rolling, a feature which is especially beneficial when the substrate material has lower yield strength than the cladding. Any tendency to curling of either

component of the assembly is immediately counteracted by the curling tendency of the other component and rolling stresses in the two components are thus equalised.

b) The effective minimum thickness capability of the rolling mill is halved by this method. If the minimum thickness capability of the mill for a single ingot is, say, 8 mm, this will represent two sheets of 4 mm thickness.

c) As the final thickness is twice that of the required thickness of the individual sheets, rolling temperatures are less quickly dissipated and are thus more readily maintained.

d) The cladding surfaces, being at the centre of the two-ingot composite assembly, are not exposed to the mill environment and are thus kept clean and free from damage.

e) As the cladding and bond interfaces of the two composite sheets are the areas where critical temperatures must be maintained, their location near the centre of the composite assembly assists in maintaining these temperatures between the defined upper and lower limits, as heat dissipation is at its minimum in this area.

f) The range of material combinations which can be explosively bonded and onward rolled is significantly extended by removing the effects of the relationship between rolling capability and the differential in the yield strength of the metals of the clad combination.

g) The technology of rolling explosive bonded composites is simplified and is comparable with conventional rolling of single steel plates.

One procedure for practising the invention is now described, by way of example, with reference to the accompanying drawings wherein

Fig. 1 is a diagrammatical elevation, partly in section of an assembly of explosively bonded clad ingots prior to rolling; and

Fig. 2 shows in perspective a view of the rolled out ingot of Fig. 1.

Referring to Fig.1 a first explosively bonded composite ingot (10) consisting of a steel substrate (12) and a metal cladding (14), is placed with the cladding (14) uppermost. On the upper surface (16) of the cladding (14) is placed a parting layer of inert material (18) to leave uncovered a 'picture frame' or margin (20) of cladding surface (16).

A second explosively bonded metal clad composite ingot (22), consisting of a steel substrate (24) and metal cladding (26) is inverted and located upon the first clad composite ingot (10) and inert layer (18) and the edges of the clad composite (22) are registered with those of the lower composite ingot (10). A steel strip (28) is sited centrally over the interface of the clad composite ingots (10) and (22) and is secured by fusion welds (30) on each side of the strip (28). This operation is repeated around the four edges of the composite assembly (32).

The assembly (32) is pre-heated to the prescribed rolling temperature and then rolled down by conventional hot rolling techniques to a thickness which is twice that of the required final thickness of a single finished clad sheet. It will be found that the clad composites (10, 22) have no tendency to curl during the rolling process.

Referring now to Fig. 2, after rolling, the extended composite (34) is levelled by conventional means and is then sheared along the lines (36) to remove the previously welded edges (30) which are themselves extended in area by the rolling operation. The thinned composite clad sheets (10) and (22) are separated to give individual bonded composite clad metal sheet of the final required thickness.

The following Examples further illustrate the practice of the invention:

EXAMPLE 1

A single clad metal ingot was produced by explosively bonding a 6 mm thick cladding plate of nickel/chrome alloy Hastelloy C276 (Registered Trade Mark) (containing about 60% Ni, 15.5% Cr and 16% Mo) onto a substrate of 30 mm thick Carbon Steel ASTM A516 Grade 70. The oreal dimension of the clad ingot was 3 metres x 1.25 metres. This ingot was bisected to form two ingots 1.5 metres by 1.25 metres. The first ingot was placed with the Hastelloy surface of the cladding uppermost, and 4 sheets of glass fibre tissue were located, one upon the other, onto this surface. The tissue layers were trimmed to leave an exposed margin of cladding plate surface around the periphery of the glass fibre.

The second ingot was inverted and placed, with the surface of the cladding plate downwards, onto the glass fibre tissue surface with its edges in register with those of the underlying first plate.

A 13 mm wide by 3 mm thick strip of steel bar was laid over the interface along one side of the ingot assembly and each edge was fusion welded to the

adjacent steel substrate. This process was repeated on the remaining 3 sides of the assembly.

The ingot assembly was heated to 1150°C and was then rolled down in incremental stages to a final thickness of 8 mm. At each incremental reduction through the rolls the assembly emerged from the rolls substantially straight with no inclination to curve in any preferred direction.

After roller levelling the 8 mm thick composite assembly, the edges of the composite assembly were trimmed to remove the bonded areas associated with the pre-welding of the assembly whereupon the two single clad metal sheets of 4 mm thickness separated.

Examination of the clad surface confirmed the presence of a clean unblemished surface over the area.

EXAMPLE 2

The method of Example 1 was repeated using a cladding layer of nickel/chrome alloy, Hastelloy C22 (containing about 60% Ni, 21% Cr and 13% Mo) instead of Hastelloy C276. In addition, the surface of the C22 alloy was coated with a suspension of chromic oxide in water and allowed to dry as an alternative separating medium to the glass tissue of Example 1. In all remaining aspects of assembly and rolling, the procedures were identical to Example 1.

The results of rolling were also identical and the rolled clad metal sheets separated easily. The two clad surfaces, on separation were coated with a layer of green chromic oxide which was readily removed by shot blasting to reveal a clean unblemished cladding surface of nickel/chrome alloy.

CLAIMS

1. A method of making explosively clad metal sheet wherein a relatively thick metal cladding layer is explosively bonded to a relatively thick metal substrate to form a composite metal ingot and the ingot is reduced in thickness and extended in area by hot rolling, characterised in that before rolling, two ingots are assembled with the cladding layers facing an intermediate parting layer of inert material and the assembly is rolled to reduce the thickness and expand the area of the ingots simultaneously.

2. A method as claimed in Claim 1 wherein the yield strength of the substrate metal is less than the yield strength of the cladding metal.

3. A method as claimed in Claim 1 or Claim 2 wherein the parting layer comprises glass fibre tissue or chromic oxide.

4. A method as claimed in any one of Claims 1 to 3 wherein the edges of the substrate of the two ingots in the assembly are bonded together by a metallurgical bond whereby the surfaces of the ingots are maintained in register.

5. A method as claimed in any one of claims 1 to 4 wherein the explosively bonded ingots have a substrate thickness in the range from 20 to 200 mm and a cladding thickness in the range from 2 to 30 mm and are rolled down to form a clad sheet having a substrate thickness in the range from 3 to 50 mm and a cladding thickness in the range from 0.5 to 5 mm.

6. A method is claimed in any on of Claims 1 to 5 wherein the substrate comprises carbon steel and the cladding comprises a nickel/chrome alloy.

7. A method of making explosively bonded clad metal sheet substantially as described with reference to the accompanying drawings.

8. Explosively clad metal sheet whenever made by a method as claimed in any one of claims 1 to 7.

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